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Summary:
Whether we look at Europe, the USA or Japan, in many areas in the world new possibilities of employing robotic systems in work settings essentially rely on direct collaborative interaction between human workers and collaborative robots leading to new distributions of agency between them and making available robotic operations as resources for performing different forms of work, work which otherwise would remain out of reach for robotic automation for the time being. In this paper we introduce our concepts of studying the social construction of these collaborative work settings and the distribution of agency, accordingly. Referring to the basic idea of actor-network theory that technology in use should be analysed in a symmetrical manner, treating all the human and nonhuman entities involved as actors, our concept of distributed agency goes beyond actor-network theory in that it introduces the notion of gradualised action, which allows distinguishing between different levels of distributed agency. Therefore, we can precisely describe, in which way and to what extent activities and actor positions are delegated to robot co-workers or remain with its human counterpart. For analysing how the distribution of agency between human and robot co-workers is socially constructed in different stages, first in laboratory settings and then in increasingly realistic real-world settings, we interpret the spectrum of manifestations of human-robot collaboration as prototypically realised scenarios at different stages of elaboration. In doing so we introduce the current state of collaborative robots in the areas of industrial production and care work as they represent contrastive cases: In industrial production collaborative robots are the next step in a long-standing history of robotic automation whereas in care work the new robots are also the first robots to be employed there. We believe that in both fields a perspective on collaborative work between humans and robots as a socio-technical constellation is helpful in order to be able to identify new distributions of work tasks.

Keywords:
collaborative robot – human-robot collaboration – situational scenario – distributed agency – gradualised action – care work – industrial production

Contents

1. Introduction

Over the last decade, a lot of academic and industrial research has been carried out to develop robots that are able to directly interact with human workers in shared workspaces in order to accomplish common tasks. Much of this research and development yet has not left the academic and industrial research laboratories. Thus, the robots developed are research prototypes or demonstrators, whose envisaged use is explored in experimental settings within the laboratories or in test settings and trial runs in controlled real-world environments. However, in sectors with a long-standing history of deploying robots such as the automotive industry, for some years collaborative robots are increasingly introduced for use in actual operation. And even in sectors such as the care sector, in which so far there has been little or no automation, there are high hopes (and fears) that with the advent of the new generation of robots able to interact with humans in everyday environments, robotic support for human work will become a reality in the foreseeable future.

Current developments indicate that co-work with collaborative robots will substantially change the relationship between human labour and technology in three ways. Firstly, for working in shared workspaces the behaviour of the robot must be adapted to the presence of the human co-workers so as not to physically endanger them or to move at speeds or on trajectories that are incompatible with human behavioural capabilities. Thus, these robots cannot have physical attributes or behavioural characteristics that would require keeping them at safe distance from humans. Consequently, collaborate robots will and are beginning to permeate human work places that previously have been closed to them. Secondly, with robots that are capable of dealing with co-present humans without endangering them or behaving incompatibly, a new level of availability of robotic operations comes into play. Here, the main aspect is that collaborative robots – in contrast for instance to traditional industrial robots, who require elaborate safety measures to be operated safely – can be deployed with much less effort in a broad variety of different work settings and that it even becomes increasingly possible to employ them within regular everyday environments. Thirdly, profiting from advances at the cutting edge of artificial intelligence, collaborative robots represent a new level of behavioural autonomy, especially with respect to taking initiative in interaction and being capable to act in less prestructured situations. However, we suggest conceiving the new level of delegation of human activities to robots not isolated but as part of the respective collaborative setting viewed as a socio-technical constellation.

2. From substitution to collaboration

A main focus in the debate on the digital transformation of work is about its employment effects. Frey and Osborne (2017, first published in 2013) have estimated that 47% of all jobs in the USA are at high risk of being automated in the next 10-20 years. The study attracted attention not only because of the extent of the predicted substitution of jobs, but also because of the kind of tasks assumed to become subject to computerisation. Especially striking is the extent to which this and other studies regard non-routine tasks performed by skilled workers, specialists and experts to be affected by digitalisation (Frey & Osborne 2017, 36-41; Dengler & Matthes 2015, 12-21; Brynjolfsson & McAfee 2011; for the medical sector see Roland Berger 2019, 13). Frey and Osbornes units of observation are entire jobs. If according to their analyses, the average spectrum of tasks of a job shows a high percentage of automatability, they assume that the entire job is susceptible to computerisation. However, computerisation and automation of work actually takes place at the level of tasks or sub-tasks rather than on the level of entire jobs (Dengler & Matthes 2015, 12). Even jobs, which according to Frey and Osborne are at high risk of being automated, often include essential tasks that are beyond the reach of algorithms and robots (Bonin et al. 2015, 14). Considering this consequently leads to significantly lower predictions of job automation.

In the past, the automation of routine tasks often led to the substitution of entire jobs since these jobs, carried out by unskilled workers, often consisted completely of such tasks. However, this logic of substitution no longer applies to the non-routine tasks that currently become subject to digitalisation. Rather, the current situation is characterised by a broad range of jobs, which include both tasks that are subject to automation and others for which this is not the case for the time being (cf. Bonin et al. 2015, 14-15). Most likely, these jobs will not be completely automated in the near future but they may change considerably. For sure, as long as automation is productivity-oriented, there will be substitution of human labour by machines with corresponding labour-saving effects. However, an important part of this change will be the emergence of new forms of collaboration between human labour and digital artefacts conducting together non-routine cognitive and manual tasks. In this sense, the focus shifts from substitution to collaboration (Decker et al. 2017).

3. Human-robot co-work in industrial production and care work

The two fields of work mentioned above, industrial production and care work, are for several reasons especially suitable for studying co-work with collaborative robots. Both are among the most prominent areas of application of collaborative robots. A considerable part of the efforts in developing collaborative robots and ideas of how to employ them is addressing one of these two fields. Additionally, they represent contrastive cases: In industrial production collaborative robots are the next step in a long-standing history of robotic automation whereas in care work the new robots are also the first robots to be employed there; also there is the contrast between production work and service work (Decker et al. 2017, 351-352; Fischer et al. 2017, 11-12).

3.1 Industrial cobots

Collaborative robots for industrial settings are often called “cobots” (El Makrini et al. 2018, 51; Peshkin & Colgate 1999). According to Hentout et al. (2019, 4) an “industrial cobot is designed for direct actuation with human co-workers in the industry to provide flexible manufacturing environment of future mixture of humans and robots and to assist them during tasks accomplishment (by reducing physical effort and cognitive overload). Additionally, industrial cobots are used to help the co-workers to lift, move production workloads […]. They can also support and relieve human operators, and place the loads quickly, precisely and safely”. The underlying idea is to combine the strengths of robots and humans: the physical strength, precision, and stamina of the robots with the human problem-solving capacity, and ability of dealing with new and unforeseen situations (Tsarouchi et al. 2016; Hägele et al. 2016, 916; El Makrini et al. 2018, 51).

In contrast to cobots, conventional industrial robots “incorporate, in most cases, simple sequences of tasks whose execution orders are static” (Haddadin et al. 2011, 264), which allow for little flexibility and adaptation to unexpected events. They operate behind secure barriers, in safety cages or behind light curtains, to keep people at a safe distance. Direct human-robot collaboration within shared workspaces is impossible with these industrial robots. They are developed and deployed mainly for capital-intensive large-volume manufacturing. About 80% of all industrial robots were installed in the automotive, electronics, and electrical goods industries, which heavily rely on this kind of manufacturing (Hägele et al. 2016, 1386). There is a stark contrast between the deployment of industrial robots in component assembly versus final assembly in the automotive industry that illustrates the limitations of conventional industrial robots (Hägele et al. 2016, 1398-1399). For producing the Audi A1 car, the Audi factory in Brussels “employs a total of 550 industrial robots in the body shop and 30 in the paint shop”, while for final assembly “only six industrial manipulators are used” (El Makrini et al. 2018, 51). There are three major reasons for this difference: First, because of the wide range of different customisations of cars, there is much more variability in final assembly than in component assembly. Second, materials such as rubber hoses or wire harnesses have to be handled that require considerable tactile capabilities. Third, compared to component assembly product assembly includes more complex tasks (El Makrini et al. 2018, 51; Hägele et al. 2016, 1392, 1399-1401).

Enabled by recent technological advances in the field of robotics, these more complex and variable work settings increasingly become amenable to robotic automation, which because of the large number of production processes of this kind is highly desirable from a productivity-oriented perspective. With respect to coping with variability, consider for instance the handling of workpieces is a typical industrial robot application. Conventional industrial robots require the workpieces to be supplied in a pre-sorted manner. Often, they are stored in special carriers or magazines, so that the robot can pick up each piece in the same predefined way from the same predefined position. Customised magazines for each part and pre-programmed motion patterns for handling them, however, render the respective assembly processes quite inflexible. More flexible assembly processes, however, would require more universal containers for workpieces. Because of advances in the robots' capabilities of "bin-picking" (locating randomly ordered parts and planning and executing the requisite grasping operation), this more and more becomes an option (Hägele et al. 2016, 1395-1396). Additionally, advances in torque-sensing and compliant force control have increased the robots' capabilities to handle sensitive materials (Hägele et al. 2016, 1399-1401). Based on these and other advances, industrial robots now are "on the verge of emerging from their cages, and entering the final assembly to work alongside humans" (Unhelkar & Shah 2015, 239). It becomes increasingly possible to employ industrial robots for less prestructured and more complex tasks, though mostly only as cobots in combination with human co-workers dealing with all the complexities of partly unstructured situations that still exceed the robots' capabilities.

Sharing the same workplace is one of the defining characteristics of human-robot collaboration (Koch et al. 2017, 84; Hentout et al. 2019, 2). The safety requirements for robots that no longer operate behind safety fences separating them from the human workforce have hindered the actual use of cobots in industrial production for some time. Meanwhile, however, a number of measures for dealing with these safety issues have been developed and standardised. ISO 10218, the international standard for robot safety, was revised in 2011 to include standards that "for the first time define human-robot-collaboration as a specific form of a robotic application in an industrial setting and provide guidelines for setting up such collaborative robot systems" (Hägele et al. 2016, 1406). The revised ISO 102018 defines four modes of collaboration between human and robot while the robot is in automatic mode: (1) Stop on access with automatic task resumption: When the human co-worker accesses the shares workspace, the robot automatically stops moving and resumes its task only after the human has left the collaborative workspace. (2) Hand-guiding: The human operator guides and controls the movement of the robot through some kind of handle positioned near to the robot's end-effector (i.e. the manipulator at the end of the robotic arm). (3) Separation and speed reduction: The human and the robotic co-worker can move concurrently in the same workspace. Their movements are continuously monitored. Safety controllers supervise the robotic movements in order to ensure a safe combination of speed and distance to the human co-worker. (4) Power and force limiting: Through the design of the robot, the possible collision forces are limited so that human co-workers robot can directly interact with the robot without being hurt in case of accidental contacts.1 Since cobots must satisfy the criteria of at least one of these modes in order to be approved for industrial use, they are quite influential for the current design of human-robot collaboration (Hägele et al. 2016, 1405-1408; Villani et al. 2018, 252-254).

The tasks for which industrial cobots are considered are largely the same as those of conventional industrial robots (handling, welding, assembly, painting, and processing), but within more dynamic working environments (Hägele et al. 2016, 1393-1405; Bo et al. 2016, 1342; Villani et al. 2018, 261-262). For this purpose, cobots are usually designed as lightweight robots that are mobile and able to be moved between different workplaces. In most cases they consist of one arm or a pair of two arms and are designed with 7 degree-of-freedom axes or joints to provide them with the required flexibility and manipulability (Hentout et al. 2019, 5). The following main aspects of collaboration between human and robot co-workers can be distinguished: (1) Assisting with supportive activities: In a shared workspace the robot performs tedious sub-tasks such as picking up, moving, and positioning materials in order to ease the human co-workers' burden of physical labour and to render their workplaces more ergonomic (Villani et al. 2018, 261). An example is the use of a cobot named "PART4you" at one of the assembly lines at Audi's Ingolstadt plant. It supports the assembly workers as an assembly assistant by picking up components such as coolant expansion tanks from the material boxes, passing them to the workers, and holding them ready to be taken by the workers (Audi AG 2015). (2) Contributing physical strength: The robots' ability of moving and holding heavy materials is used to relieve the human co-worker from strenuous sub-tasks. In this manner, a KUKA robot in a pilot project in Ford's assembly plant in Cologne helps workers fitting shock absorbers to Fiesta cars (Lelinwalla 2016). (3) Contributing technical precision: The robots' ability of moving and manipulating materials very precisely is used to support the human co-worker in performing high-precision tasks. An example is the gearbox production at the Skoda plant in

[1] The power and force limiting mode has been further developed by ISO TS 15066 published in 2016, which in detail specifies biomechanical limits (Fachbereich Holz und Metall der DGUV 2017).

Vrchlabí, where collaborative robot aids the human workers in inserting the gear actuator piston, which is one of the most delicate manufacturing steps (Volkswagen AG 2015). (4) Contributing human skills for dealing with complexity and variety: The humans' ability to deal with changing situations is used to help the robot to adapt its activities to dynamic work environments. A use case at Audi Brussels provides an example, where a cobot named Walt is employed to apply glue on different kinds of car parts at different assembly lines. The human co-worker instructs the robot with hand gestures at which assembly line it should work next and which kind of car parts are there to be worked at (El Makrini et al. 2018, 54-57). (5) Task teaching: The hand-guiding cooperation mode builds the basis for walk-through programming. This is a robot programming method, which is fast and flexible, can be conducted by every skilled worker, and does not presuppose special programming skills. The worker programs the robot by guiding the end-effector of the robot through the positions that constitute the trajectory to be programmed. The robot controller records the movement pattern. Based on the record the robot is able to reproduce the trajectory (Villani et al. 2018, 258).2

So far, there is little research from the social sciences on industrial human-robot collaboration (Moniz & Krings 2016, 2; Fischer et al. 2017, 9). Most research from work science and human-robot interaction focusses on ergonomic and safety issues (Weber & Stowasser 2018, 232-234) or addresses qualification needs of workers in human-robot collaboration (Schüth & Weber 2019). Additionally, there is some conceptual work on the characteristics of human-robot collaboration. Several researchers have suggested to define human-robot collaboration by direct concurrent interaction in shared workspaces and to distinguish it from sequential co-work in shared workspaces (Koch et al. 2017, 84; Weber & Stowasser 2018; Hentout et al. 2019, 2). It is, however, questionable if this distinction is useful. Consider for instance the precisely coordinated alternation between human and robotic manipulations in the collaborative assembling of sockets with child protection at a Czech ABB plant (Automationspraxis 2018; https://www.youtube.com/watch?

[2] Though the direct interaction between the robot and the human co-worker occurs only during the teaching and, subsequently, the task may be conducted by the robot alone and without further collaboration, the whole setting should be viewed as collaborative because it includes skilled human workforce is an irreducible component. Interestingly, for this very reason an early predecessor of walk-through programming, the record playback technology, was abandoned. In the mid of the 20th century, there were two competing ideas of how to automatize machine tools: record playback and numerical control. According to David Noble (1978, 327-338), back then the managements aim to minimise the dependence of capital upon skilled labour was one major reason for them to prefer the development of numerical control over record playback technology.

v=aKw5hoRcCxc). Such a setting of sequential co-work represents a much more interactive collaborative setting than a concurrent interaction, in which the robot for instance just holds a workpiece in the right position for the human co-worker to fasten it in place.

Probably the most influential conceptual approach for analysing and designing human-robot collaboration from a work science perspective is the contrastive task analysis (cf. Volpert 1987), which focusses on the complementarity between the strengths of robots and humans. Again, the main idea is to combine the strengths of humans and robots, based on the corresponding assumptions about particular strengths of humans and robots: Humans are superior to robots in handling of complex decisions and working in complex and changing environmental situations. Robots are superior to humans in moving heavy items, in performing movement patterns with difficult trajectories, in executing monotonous activities and in perseveringly repeating them with high accuracy, and in working with high precision (Weber & Stowasser 2018, 232). Accordingly, tasks for human-robot collaboration are analysed capability-oriented. That is, for each sub-task the capabilities required are assessed in detail, whereupon these sub-tasks are assigned either to the human or the robot co-worker and the work process is designed respectively (Beumelburg 2005).

The academic and industrial researchers developing cobots, the experts from work sciences and human-robot interaction designing the collaborative work processes, and the manufacturers implementing them, they all characterise the new human-robot collaboration usually in its most positive way: The cobots assist the human workers, they relieve them from strenuous, tedious, and repetitive tasks, but do not replace them. Employing them makes the workplace healthier and more ergonomic; at the same time, it enhances the flexibility of production processes. However, in all these aspects, the picture is more complex than that. Though giving assistance to human workers is a common way to employ cobots in collaborative settings, there are also collaborative settings, in which the human worker assists the robot or in which both give and get assistance to and from each other. The fact that in human-robot collaboration repetitive sub-tasks are assigned to cobots does not necessarily mean that human work becomes more challenging. Often, the sub-tasks assigned to the human co-workers are also quite monotonous and remain human tasks only because they cannot be automated with reasonable effort (as in the example of the collaborative assembling of sockets mentioned above). This calls for a more encompassing analytical perspective on the distribution of tasks among human and robotic co-workers that focusses on the socio-technical constellations constituted by the collaborative settings as relational structures rather than just considering the capabilities of the human and robotic agents involved in them. Contrastive task analysis

– and especially the idea of complementarity – can serve as a useful starting point for such a relational view on human-robot collaboration. But only, if it is acknowledged that complementarity is itself a relational property and not just a result of given capabilities of humans or robots.

The same applies with respect to flexibility. This is important, because flexibility is the performance characteristic that more than anything else distinguishes human-robot collaboration from other forms of technology-supported industrial labour. Flexibility should also be viewed as a property of the overall system (Lenz 2011, 2) and not primarily as derived from particular capabilities of the collaborating humans or robots. Surely, the cobots' advanced capabilities of dealing with less prestructured environments contribute to the flexibility of human-robot collaboration. So does the human co-workers' capabilities of coping with changing situations (Pfeiffer 2016, 23). Another factor is the flexible applicability of cobots to different tasks, resulting from simpler programming and the lack of safety cages. However, the flexibility of the existing and the envisaged human-robot collaborations result from quite different combinations and usages of these (and other) factors. Thus, it requires to focus on the collaborative constellation as a whole and on the relational structure of its components to analyse its different forms of flexibility. Till now, there is little research on industrial human-robot collaboration from such a more encompassing view (Moniz & Krings 2016, 10-11).

3.2 Care robots

Care robots are service robots "that operate partly or fully autonomously performing care-related activities for people with physical and/or mental handicaps. These handicaps are related to age and/or health-related restrictions" (Goeldner et al. 2015, 115). The intended use of care robots is to assist care workers or to relieve them from the most tedious and repetitive parts of their workload. Like other service robots (Schraft et al. 2004), care robots are envisioned to perform tasks in unstandardised environments and in direct interaction with the service recipients. Early design studies and research platforms (e.g. Carnegie Mellons Nursebot PEARL; Pineau et al. 2003) aimed at robots capable of carrying out a broad spectrum of care work tasks (e.g. natural speech conversation with the robot, pick-and-carry tasks, navigation and guiding, walking aid and reminder) but have not been successful. Subsequent research and development focused on the incremental improvement of functional components necessary for a care robot, leading to a variety of approaches for single-task care robots. In recent years, the technical advances in robot components are perceived allowing to seriously tackle the "human frontier" (Inoue 2008), opening the possibility to introduce service robots into complex work environments such as care work.

Most authors classify the tasks to be carried out by care robots with reference to the different needs of the care recipients (e.g. Martinez-Martin & del Pobil 2018; Vercelli et al. 2018). However, since we are primarily interested in the relationship between care robots and human care workers and not in the relationship between care robots and care recipients, the following classification is more useful. It is based on the range of human care workers' tasks (Niemelä & Melkas 2019; ROSE Consortium 2017): (1) Transport and logistics: Commercial applications are in use in some hospitals and nursing homes, e.g. Aethons TUG which autonomously delivers "pharmacy medications and laboratory specimen and heavier loads such as meals, linens, and environmental services" (www.aethon.com). (2) Physical assistance: Commercial prototypes for beds convertible into wheel chairs are in the prototype stadium (e.g. Resyone by Panasonics) and diverse variants of semi-autonomous lifting devices, most of them based on an explicit modelling of body movements, are investigated with laboratory platforms like RIBA (Mukai et al. 2010). (3) Monitoring and data acquisition: Robotics components for locating residents of nursing homes, detecting critical situations and acquiring basic health data (with questionnaires) are available and tested using commercial standard robots like Pepper (e.g. Van der Putte et al. 2019). (4) Telepresence: Basic robot platforms for remotely controllable robots (eventually supplemented with autonomous robotic collision control) and some remote sensing functionalities can be bought from the shelf. Functionalities range from simple tablets on wheels with two-way audio communication (e.g. the VGO robot for remote visiting; see https://youtu.be/yjgq3dR2s1o) to combinations of taking patients' pulse, scanning vital signs, taking pictures and reading case notes (e.g. RP7, http://www.intouchhealth.com). Basic research aims at enhancing the physical properties of a robot to allow remote control of a "robot nurse". Li et al. (2017), for instance, introduce the explicit modelling of all of a nurse's main caregiving tasks, the physical realisation of a respective robot and the subsequent evaluation of the robot. (5) Cognitive assistance: Prototypes of small robotics devices, often in a toy-like form, are tested in real world environments for relieving care workers from cognitive assistance tasks like medication management, repetitive reminders or motivation to exercise (Martinez-Martin & del Pobil 2018, 79-94). (6) Companions: Robots like PARO, which looks and feels like a baby seal, are designed with limited functionalities to evocate the creation of affective bonds to the robot (Chang & Sabanovic 2015). The robots are used in pilot projects in nursing homes for therapeutic purposes especially with patients with dementia.

For the single-task care robots, basic stand-alone robotic solutions are already commercially available. More elaborated versions are currently developed in academic and industrial research.

The ultimate challenge of care robotics, however, are robots able to carry out a multitude of different caregiving tasks. The typical design of multitask care robot prototypes consists of a wheeled case with an assortment of sensors, a central communication and control device (mostly a tablet) and one or two robotic arms. There are original designs where all major software and hardware components are developed in the research laboratory, such as the prototype robot of the EU project HOBBIT (Vincze et al. 2014; http://hobbit.acin.tuwien.ac.at/index.html). It is equipped for autonomous navigation, interactive communication, picking up objects, transporting objects, emergency recognition, fitness training, and giving reminders, including learning capabilities for adapting to the care recipients' habits and preferences. In contrast, derivative designs enhance existing (and often commercially available) basic hardware and software platforms with new functionalities. An often cited example is the software extension of the standard platform NAO (well known for robot soccer) making use of the robot's functionalities like walking, talking, and dancing for therapeutic purposes (Huisman & Kort 2019). Another example is Toyotas Human Support Robot (Yamamoto et al. 2018, https://www.toyota-global.com/innovation/partner_robot/robot/#link02) with its standard functionalities of picking-up, fetching, remote communication and autonomous navigation. Even the most ambitious approaches to multitask care robots acknowledge that an overall replacement of human care work by care robots is far out of reach (van Aerschot & Parviainen 2020). Rather, the tasks to be carried out by the robots have to be embedded into sequences of activities distributed between the robots and the human co-workers. Accordingly, the collaboration with human care workers is often explicitly modelled as part of the robots' control architecture, for instance as mixed-initiative human-robot interaction (Jiang & Arkin 2015). The vast majority of these robots are in early or advanced development. Van Aerschot and Parviainen see the main reason for this less in the social acceptance of robots as machines that take over care tasks, but rather in the difficulty of being able to cope with the complex "ecosystem" of care, which refers to a care facility, hospital or any other place where care is provided and received and in which care recipients, caregivers, the supporting family and friends, and various tools and technologies all play a role and should be considered in their sociotechnical interrelations. Therefore, "[t]he complexity of social, emotional and physical human needs and processes, seem to be somewhat distant or difficult to capture in the design of robots. The neediness, frailty and vulnerability that come along with decreasing physical and cognitive capacity are not easy, or perhaps not at all possible, to meet with care robots" (van Aerschot/Parviainen 2020: 5).

Despite a growing interest in the topic of care robotics (Bendel 2018), the majority of research in the social sciences are quantitative studies on the acceptance or acceptability of the robots by the care recipients (Pu et al. 2018; Broadbent & al 2016). Most of the qualitative research from the sociology of work and care sciences are about technical relief from boring or dull tasks, or address the fear of substitution of human work by automation on the other hand. There is a demand for more encompassing sociological analyses of human-robot collaboration in the field of care work. However, this requires elaborating on the concept of care work.

The conception of care work from the perspective of the social sciences is based on the assumption that sentimental work is the central "ingredient in any kind of work where the object being worked on is alive, sentient, reacting" (Strauss et al. 1982, 254). Care work, thus, is at the same time provision of care-related services instrumental for the physical well-being of the care recipients ("Versorgungsarbeit") and sentimental work ("Sorgearbeit", or "Beziehungsarbeit"). Caregivers always have to face the emotional reactions of the care receivers to the "instrumental" (medical, physical, administrative) components of their work. The care workers' arc of work, then, is portrayed as "mixes of work", as a "complex interplay between the standard occupational assignment of tasks and the subtle weaving in and out of occupationally sentimental work" (Strauss et al. 1982, 270). In a recent formulation, Remmers (2018, 167) describes this as the necessity of synchronising the provision of services with personal affection and affective balance.

From the dominant perspective in care science, care as provision of care-related services and care as sentimental work are inextricably linked. According to this view, delegating care-related service tasks to technology (or, for that matter, to nonskilled labour force; Wright 2019) inevitably has negative effects on sentimental work and upsets the precarious balance between the instrumental and affective components of care work. This position provides the background for the more recent discussion about the consequences of introducing robots into the domain of professional care, taking place in care science (Hülsken-Giesler 2018) and in technology assessment (Kehl 2018). In contrast, the prevailing view of state agencies, who promote the development of care robots as a measure for solving the nursing crisis, imply a dichotomous view. According to this view that is shared by most developers of care robots, both aspects of care work can be delivered separately. Thus, it would be desirable to have care robots carrying out the dull, repetitive, and physically or mentally exhausting tasks giving the human care workers more time for care as sentimental work (Krings et al. 2014).

However, there is some evidence that both positions are too simple. For instance, Pols and Moser (2009) reject the principal ontological divide between "cold technology" and "warm care" by showing that the build-up and maintenance of affective and social relations is not restricted to human care work. Remmers (2018, 163) argues that with respect to care tasks in areas of intimacy and shame robots due to their impersonal nature might be preferred over human caregivers. Additionally, some empirical studies on robot companions show that the creative adaption of these robots in practices of work and mutual sense-making opens new possibilities of professional care work (Pfadenhauer & Dukat 2015; Chang & Sabanovic 2015). These findings indicate that there are quite different ways to distribute the provision of care-related services between human care workers and care robots as well as different ways to include or exclude affection. Accordingly, there are different constellations that lead to an appropriate balance between care as service provision and care as sentimental work. Similar to flexibility in the case of industrial human-robot collaboration, this balance, thus, should be viewed as a property of the socio-technical constellation of care work as a whole and of the relational structure of its human and technical components.

Recently, the concept of "arrangements of care" (Blinkert 2007), has been introduced in care science to get to a more holistic and relational perspective on the care sector. By arrangements of care, care scientists refer to the interplay between care decisions on the micro-level, larger organisational structures, and the legal and financial framework. The concept provides a relational view that care scientists hope will help to identify changes in the care sector, including the distribution of different forms and constellations of home care and care facilities. The aspect of globalisation for the care sector (for global "chains of care workers" see Hochschild 2001) is also addressed by Wright (2019) who shows for the case of Japan that the government's goal of replacing unskilled immigrant workforce with robots led to unexpected outcomes due to the multiple interrelations within the whole constellation. Compelling examples include an unintended increase in workload on the side of the native care workers, and the unforeseen situation where robots are used to teach immigrant novices in basic care work tasks. These are examples of unintentionally upsetting the balance of care constellations.

The mostly ethnographic empirical studies on the organisational consequences of the introduction of robots in care settings stress that the perception and use of these artefacts strongly depends on different forms of organisation of workflow and organisational hierarchies (Mutlu & Forlizzi 2008, with respect to the use of transport robots in care facilities). Studies with a background in structuration theory focus on collective processes of making sense of the robots, on how the new technology serves as an occasion for restructuring of professional identities and organisational roles (Siino & Hinds 2004), and this affects "workers' skills, jurisdictions, status, and visibility" (Barrett et al. 2012, 1448). However, these studies are interested mainly in the organisational changes triggered by the introduction of new technology and not so much in organisational changes that react specifically to particular technological features or vice versa to adaptations of the new technology reacting specifically to particular features of the organisation.

Just as in the case of industrial human-robot collaboration, the state of the art concerning human-robot collaboration in care work, thus, shows a demand for further research. In the current phase of digitalisation of work, the assumption is justified that maintaining the balance between "Versorgungsarbeit" and "Sorgearbeit" is as important for care work as enhancing flexibility is for production work. For analysing how the introduction of care robots affects this balance, a perspective is necessary that focusses on care work as a socio-technical constellation constituted by the relational structure of the human and non-human actors and agencies involved. The concept of arrangements of care and the organisation restructuring approach may serve as a starting point. However, neither of the two approaches pays enough attention to the changes in the allocation, distribution, and organisation of work that are specific to the introduction of collaborative robots.

4. Investigating the social construction of robots as co-workers in collaborative work settings

The aim is therefore to analyse the social construction of robots as co-workers within collaborative work settings in order to better understand how the distribution of work tasks and the organisation of work is going to be affected by the introduction of this new form of robots. To this end, we focus on how the different physical manifestations of human-robot collaboration serve as positions, as statements and as arenas of negotiation in ongoing processes of social negotiation of possible uses of collaborative robots. Especially, we focus on three different manifestations: (1) robot prototypes with corresponding experimental work settings in the laboratory; (2) test and trial runs of more fully developed prototypes in more realistic work situations; and (3) real-world applications of human-robot collaboration. As we will explain in more detail below, the particular design of a collaborative robot and of the work process in which it collaborates with human co-workers represents a particular position about how and for which purposes to use collaborative robots. Thus, each of these designs can be interpreted as a statement in a process of social negotiation of possible (or impossible) and desirable (or undesirable) uses of collaborative robots and, accordingly, as an opportunity for contesting, modifying or supporting the assumptions and claims it contains, thus turning the design into an arena of negotiation. For reconstructing the positions inscribed in the physical manifestations of human-robot collaboration, it is therefore necessary to analyse in detail, how the work task to be carried out is distributed between the human and the robot co-workers.

Against the backdrop of the state of the art as described above, there is reason to believe that the next stage of how robotic systems permeate the worlds of work is in essential respects penetration by collaborative robots. Increasingly, settings of collaboration between human and robotic co-workers play an important part in making available robotic operations as resources for performing work, work which otherwise would remain out of reach for robotic automation for the time being. The new possibilities of employing robotic systems in work settings, which are currently developed and explored in laboratory settings and are partly already realised in real-world applications, essentially rely on direct collaborative interaction between human workers and collaborative robots. In studying how human-robot collaboration is envisioned, experimented with, and tested in laboratory settings and in increasingly realistic work environments, and how it is already partly implemented in real-world applications, the proposed project contributes to analysing and understanding this next stage of permeating and making available.

When academic and industrial researchers develop the new forms of human-robot collaboration, they refer to assumptions about what is technically feasible and to assumptions about what is socially (in the broadest sense of the term) desirable. However, there are quite different positions about what is socially desirable leading to different ideas about which goals the development and use of collaborative robots should serve. For instance, with respect to industrial cobots, the list of desirable goals includes production flexibility, productivity, product quality, workplace ergonomics, and relieving human workers from tedious and strenuous work. Obviously, the relevance and meaning of these goals are different for the different groups of actors, who eventually will be affected by the use of these robots in one or another way, for the human co-workers for example in contrast to the production planners or the plant managers. When academic or industrial researchers develop and design a particular setting of human-robot collaboration, they inevitably prioritise between the different possible goals, consciously or unconsciously taking account of certain of these goals, while paying less attention to others. Consequently, each of these settings of human-robot collaboration represents a particular position with regard to the different goals and the interests and concerns associated with them, a position that is inscribed in the particular way the respective work tasks are distributed between the human work force and the robots. Consider as an example the collaborative assembling of sockets mentioned above. In this case, the human and the robot co-worker both carry out repetitive sub-tasks, and it seems that the reason for assigning these sub-tasks to the humans or the robots mainly lies in the difference between repetitive sub-tasks that can be automated with reasonable effort and other repetitive sub-tasks that cannot. In this case, then, the collaborative work setting represents a position where productivity plays a role, and maybe also product quality and work ergonomics, while the goal of relieving workers from boring tasks is not taken into account.

We interpret the positions embodied in the design of collaborative robots and the respective collaborative work settings as positions in ongoing processes of social negotiation about how and for which purposes collaborative robots should be developed and used. There are different manifestations of collaborative robots and work settings: (1) In earlier stages of the development, the robots are prototypes or demonstrators, whose envisaged use is explored in experimental settings within the laboratories. (2) In the further course of development, more fully developed prototypes are tested in controlled real-world environments. (3) Another manifestation is the implementation of a collaborative robot for actual use in real-world applications of collaborative work. These different manifestations represent different stages in the process of social negotiation. With the implementation for actual use, the negotiation process temporarily comes to a closure, but does not necessarily end. When speaking of a process of social negotiation, we do not imply that there are direct negotiations between the different groups of actors sharing particular interests and concerns with respect to the new socio-technical constellation under development. Rather, most of these interests and concerns are represented more indirectly.

Also, these social negotiations do not take place without context, but are in particular ways socially prepared and technically enabled. An important driving force preparing the ground for collaborative robots are powerful societal narratives that assign to robots an important role in dealing with basic societal problems. In both fields of work we have chosen for our empirical research, industrial production and care work, there are narratives of this kind. The probably most powerful narrative used to explain why innovation is imperative in today's industrial production is about the need for more flexible production amid changing market conditions that require shorter development cycles and more customised products. Accordingly, the high degree of standardisation of today's production machinery is perceived as the major bottleneck that has to be overcome to get to more flexible forms of production. As our review of the state of the art has shown, enhancing production flexibility is also a key promise – maybe the most important promise – associated with the development and use of industrial cobots. Thus, taking into account the influence of the flexible innovation imperative must be part of the empirical analysis of the social construction of industrial cobots. With respect to the care sector, the probably most influential narrative is about digitalisation as a means to deal with the nursing crisis, i.e. the expected dramatically increasing shortage in human care workers due to the demographics of ageing societies. Ideas about how to delegate parts of care work to semi-autonomous machinery and especially to robots are strongly pushed by state agencies and public opinion leaders. However, these ideas and the underlying narrative are also strongly contested in the discourse of care science and by care professionals, articulating the dystopic side of the same narrative. As described, an important aspect this narrative is the promise that care workers will be released only from dumb, physically challenging or repetitive tasks, giving them more time for sentimental work. By this promise, the narrative is closely connected to the key concern of care work to keep the balance between care as service provision ("Versorgungsarbeit") and care as sentimental work ("Sorgearbeit"). Thus, taking into account the influence of this narrative (and its dark side) must be part of the empirical analysis of the social construction of care robots.

For both fields of work, the narratives mentioned favour technological over non-technological solutions for the respective problem. For industrial production with its long-standing history of technological rationalisation, this is not surprising. For the care sector, however, it is. Here it becomes particularly clear, why technical enabling is an important context for the social construction of collaborative robots. In the last decades, the technical functionalities of many robot components have been enhanced up to the point where direct interaction with human workers in ill-structured workspaces has come into reach. The most important advances are: (1) More fine-grained sensors, sensor data processing and navigation procedures that allow safe human-robot interaction. (2) New materials and kinematics of actuators for direct physical manipulation. (3) Advanced designs and algorithms for learning unknown situations and enhancing planning capacities. (4) New types of control architectures that enable the robots to share their task execution with human co-workers, e.g. in the programming of "mixed initiative systems" or by learning the execution of tasks from human instructors. Many of these technological advances result from basic research. Not being developed for the particular circumstances and requirements of specific domains of application, they are potentially useful for many possible applications. As typical for technological innovations in their earlier stages of development, this evokes the mechanism of "solutions looking for a problem", which is at least in domain of care work probably a major factor in the social construction of care robots for collaborative work settings and play a role in the development of industrial cobots as well.

5. Analysing prototype scenarios at different stages of elaboration

For analysing how the distribution of work between human and robot co-workers is socially constructed first in laboratory settings and then in increasingly realistic real-world settings, we interpret the spectrum of manifestations of human-robot collaboration from robot prototypes in experimental settings to first real-world applications as *prototype scenarios at different stages of elaboration*. By building prototypes of a new technology under development and the corresponding testbeds, the underlying situational scenarios more and more become physically realised. Engineers are usually eager to do so in the early stages of their work in order to test, demonstrate and evaluate their ongoing work and in order to arrive, as early as possible, at a proof of concept by showing that the technological solution, at least in principle, works as intended. Testing new technology means evaluating if the new technology acts as expected within its designated context of use and proves to be useful. Hence, in test situations of this kind the prototype represents the new technology, or at least its most relevant new features, while the testbed represents the envisaged context of use, or at least some of its main characteristics. Consequently, every constellation of technological prototypes and corresponding testbeds embodies an underlying situational scenario. It embodies a particular idea about how the technology – as represented by the prototype-and the users, and other relevant components and circumstances – as represented by the test bed should interact in typical future situations of use. By prototype scenarios, we refer to this kind of prototypically realised situational scenarios (Schulz-Schaeffer & Meister 2015, 167; 2017, 204).

In prior work, we derived from detailed case studies on ubiquitous computing three major functions and uses of situational scenarios in processes of technology development: (1) successive specification of the components of the new socio-technical constellation under development; (2) evaluation of its performance, and (3) demonstration of the overall approach represented by the realised scenario. Furthermore, we identified two types of guidance of technology development by scenarios: In technology-oriented guidance, the characteristics of the envisaged situation and context of application trigger the search for fitting and suitable technological features. In application-oriented guidance, the technical features of the envisaged new technology is guiding the search for contexts of application where these features might be useful, and eventually the construction of respective situations of use (Schulz-Schaeffer & Meister 2015, 172-172; 2017, 203).

Constructing situational scenarios means to interrelate components by adapting them to each other. Defining one component in a particular way requires changing other components accordingly, in order to align their activities and to make sure that the scenario as a whole provides the envisioned features. This applies even more physically realised scenarios where achieving consistency in the interaction of the components is stronger constrained than in narrative scenarios. This is due to the physical realisation of components, which, then, have to some extent real-world properties and constraints even if only realised in a simplified laboratory setting. Introducing a new component or changing a component's characteristics requires changing other components' characteristics in order to maintain a scenario's internal consistency. Thus, situational scenarios contain decisions about which components would induce others to change and which components would have to be modified (or exchanged), if this scenario became reality. These decisions have implications for which of the parties involved would profit from these changes in the imagined future and which parties would have to adapt to them. For this reason, we believe it necessary to conceptualise the process of building, specifying and evaluating situational scenarios by which the scenario's components and their characteristics take shape as a negotiation process. Accordingly, every physical realisation of a scenario can be interpreted as a position or statement about what uses are desirable for whom and who has to contribute in which way to the new socio-technical constellation under development (Schulz-Schaeffer & Meister 2019, in press, 41-47). At the same time, they can be interpreted as opportunities for contesting, modifying or supporting the assumptions and claims they contain, thus turning them into an arena of negotiation. By referring to Anselm Strauss' concept of arena (Strauss 1993, 212-213, 226-227), we emphasize the role of prototype scenarios as a focal point where the perceptions and interpretations of all groups of actors, who are directly or indirectly taken into account in the innovation process, are brought into contact. For analysing how new socio-technical constellations are socially constructed via physically realised scenarios, it is essential to closely examine if and how the groups of actors, who eventually will be affected by the new technology, are represented within the scenario, since this determines the influence of the respective perspectives and interests. For instance, in the prototype scenarios of ubiquitous computing innovations, we studied in previous work, the envisaged future users were in some cases represented by representatives of the group of the imagined future users. In other cases, they were represented by expert knowledge derived from literature, and in yet another cases only by the technology developers themselves impersonating the imagined users in test situations (Schulz-Schaeffer & Meister 2019, in press, 49-62).

For reconstructing the positions and views about how and for which purposes to use collaborative robots that are inscribed in a given prototype scenario of human-robot collaboration at every stage of its elaboration, we refer to the concept of gradualised action within socio-technical constellations of distributed action (Rammert & Schulz-Schaeffer 2002; Schulz-Schaeffer & Rammert 2019, in press). We conceive socio-technical constellations as relational structures of distributed agency, of agency distributed between humans and technology. Distributed agency is a relation of distributed activities, if one focusses on performance (e.g. on collaborative task accomplishment). It is a relation of distributed actor positions, if one focusses on structure (e.g. on job descriptions, work skills, task responsibilities). In this way, the concept links the analysis of task distribution with the analysis of the organisation of work. Our concept builds on the basic idea of actor-network theory that technology in use should be analysed in a symmetrical manner (Callon & Latour 1992, 348), treating all the human and nonhuman entities involved as actors, whereas “any thing that does modify a state of affairs by making a difference is an actor“ (Latour 2005, 71; cf. Latour 1992, 303). However, our concept of distributed agency goes beyond actor-network theory in that is introduces the notion of gradualised action, which allows distinguishing between different levels of distributed agency (cf. Rammert & Schulz-Schaeffer 2002, 44). In recent publications, we have elaborated on our concept of gradualised action by distinguishing between an effective, a regulative and an intentional dimension of agency (Schulz-Schaeffer 2019; 2019, in press; Schulz-Schaeffer & Rammert 2019, in press). Accordingly, the effective dimension covers the ability to bring about the changes necessary to achieve certain goals of action, the regulative dimension includes the control over the execution of action, and the intentional dimension is about owning the goals. The main advantage of the gradual perspective on distributed agency is that it allows for any constellations of distributed agency to precisely describe, in which way and to what extent activities and actor positions are delegated to robot co-workers or remain with its human counterpart and how their activities and roles are interrelated in socio-technical constellations.

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